COMPRESSIONAL STRAIN HISTORY OF MERCURY. Roger J. Phillips, *Department of Earth and Planetary Sciences, Washington University, St. Louis MO 63130, USA, phillips@wustite.wustl.edu*, Sean C. Solomon, *Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC 20015, USA*.

Introduction

Lobate scarps on Mercury, interpreted as compressional in origin [1,2], formed over a period of Mercury's geological history and provide a strong constraint on the thermal evolution of the planet [3]. Here we investigate Mercury thermal histories that might reproduce the amount of inferred strain over a specified interval of time.

Solomon [3] examined the effect of overall liquid core formation and of the subsequent solid inner core formation on the surface tectonics of Mercury. He came to three important conclusions: (a) The heat produced by core infall from an initially molten planet would have *increased* the planetary radius by about 17 km; if such an event took place, it predated the present surface. (b) Complete solidification of a liquid core would have *decreased* the planetary radius by 17 km. A substantial amount of solidification would have to predate the oldest parts of the surface, which is probably inconsistent with the present-day existence of an intrinsic dipole magnetic field [4]. (c) The slow, secular cooling of the planet leads to a contraction, mainly in the lithosphere, corresponding to a 2 km decrease in planetary radius. This is consistent with the compressional strain estimated from the scarps.

The total amount of compressional strain recorded by the lobate scarps is estimated to lie in a range of about 0.04 to 0.10%, which corresponds to a decrease in planetary radius of 1 to 2 km [1,2]. The timing of lobate scarp formation is not clear. Many scarps are disrupted by large impacts, indicating scarp formation may have occurred doing and towards the end of heavy bombardment [1], coincident with intercrater plains formation. But scarps transect the younger smooth plains [2], suggesting that scarp formation continued past smooth plains emplacement, and this is consistent with the relatively uniform distribution of scarps on the surface [1,2]. Since many scarps were undoubtedly obliterated during the period of heavy bombardment [1], any model using the estimated compressional strain as a constraint must calculate cumulative strain forward in time from this period. We adopt a nominal reference age of 4 Ga for model calculations (but also examine models using 3.6 Ga). We explore thermal histories that might produce no more than about 0.1% compressional strain and at the same time have only a limited inner core growth. Of particular interest is whether model strain accumulates relatively rapidly after 4 Ga, or is more evenly distributed in time.

Method

Thermal stresses in an elastic lithosphere arise from both the cooling of this shell below the elastic blocking temperature and the volume-induced changes beneath the shell [5]. The latter is related to both temperature changes (through the coefficient of thermal expansion) and pressure changes (through the bulk compressibility). We adopt a parameterized convection approach using the conservation of energy equations [6], which provide a thermal history that includes the growth of a solid inner core. The thermal lithosphere boundary follows the evolution of a specified isotherm and the crust can grow with time, fractionating heat sources from the mantle [7]. We use the solution for the thermoelastic stresses in a spherical shell [8], with the inner evolving radius of the shell defined by the elastic blocking temperature, T_b. The two integration constants in the solution, C_1 and C_2, are found by the vanishing of normal stress at the surface and continuity of horizontal normal strain at the inner boundary of the shell. Strain rate in the shell is determined from $\dot{C}_1$ and $\dot{C}_2$, which are found analytically, given the numerical convection solution as a function of time. We examine percent of accumulated strain as function of time, as well as present-day total strain and solid inner core radius.

Results

We investigated a suite of models by varying thermal lithosphere base temperature, T_l; activation energy for creep, E; Nusselt number parameter, β; elastic blocking temperature, T_b; and reference age for contraction, t_R. Additionally, we considered contraction beneath the elastic lithosphere dominated by core cooling alone or mantle cooling alone (as end members). We examined cumulative strain, given by $E(t) = \int_{t_R}^{t} \dot{\epsilon}(t')dt'$, as a function of age, t, where $\dot{\epsilon}(t)$ is strain rate. The most useful way to examine this result was as a percentage normalized by present value; this is specified by $E_n = [E(t)/E(0)] \cdot 100$.

Figure 1 shows the solution envelope for a number of thermal history models. The following parameter ranges are represented — T_l: 1300 $\rightarrow$ 1600K, β: 0.25 $\rightarrow$ 0.40, and T_b: 400 $\rightarrow$ 1200 K. We varied E/R (where R is the gas constant) from 35,000 to 45,000 K. At 40,000 K, dynamic viscosity varied over the range $1.5\text{x}10^{20}$ to $1\text{x}10^{23}$ Pa s for a temperature range 1500-2000 K (typical of model convecting temperatures). At E/R values higher than 45,000 K, the models were characterized by early *extensional* strain. We also tested core cooling versus mantle cooling in these runs. The results leading to the envelope of Figure 1 are not exhaustive in that we did not run all possible combinations of the parameters. Nevertheless, we feel that the envelope is fairly robust over the parameter range. Starting at 4 Ga, most of the compressional strain accumulates early in these models. At the left extreme, 70% of the strain has accumulated by 2.3 Ga, and 90% by 1.1 Ga. The initial mass fraction of a light alloying element in the model cores was 0.05. With one exception, none of these models produced a solid inner core (the one case had a radius of 1160 km).

These models produce a range in accumulated compressional strain percentage of 0.20 to 0.29%, well in excess of the upper limit of the range inferred from observation. There are ways to lower the model strain. Reducing the onset time of strain accumulation decreases the total amount of accumulated strain because the accumulation time is obviously less but also the average rate of cooling is smaller. Reducing t_R to

3.6 Ga leads to a compressional strain accumulation of about 0.15 to 0.20%. Increasing β also tends to decrease total strain accumulation, as well as increase the strain accumulation rate. Finally, reducing the coefficient of thermal expansion, α, from its adopted value of $3\text{x}10^{-5}$ K^{-1} decreases the accumulated strain in an almost proportional manner.

Discussion and Conclusions

These results are preliminary, the modeling is far from exhaustive, and different approaches to boundary layer theory could be used in the parameterized convection formulation. Nevertheless, they are interesting in that it is difficult to limit the present models to the observationally inferred strain. Since all but one model had no inner core growth, we might conclude that inner core solidification is therefore not required to produce the estimated surface contraction. A question is also raised as to whether the observed value is an underestimate. Poor lighting angles and resolution limitations could certainly lead to an underestimate of the total lobate scarp population [1]. Older scarps may be have been obliterated by impact features or intercrater plains burial, although we partial account for this in the t_R = 3.6 Ga models.

New observations capable of being made from Mercury orbit would advance enormously our ability to constrain the thermal history of the planet. Imaging of the 55% of the planet's surface not seen by Mariner 10 would allow important tests of current global geological and tectonic histories [1,2]. Higher resolution (hundreds of meters or better) imaging than provided by Mariner 10 would permit tests (e.g., from transection relationships) of the interpretation that scarps are generally compressive features, and would extend the observations of scarps to smaller features than could be resolved by Mariner 10. Such imaging, particularly if accompanied by geochemical remote sensing and spectral mapping, would yield an improved understanding of global geological units, including the history of magma production and volcanism. The distribution and density of scarps and impact craters on such units would give distinctly sharper constraints than now available on the history of global horizontal strain and thus on interior cooling and core solidification. Finally, measurements of the planetary gravity field, spin axis orientation, and physical libration amplitude would give the planetary moment of inertia, thus constraining the core size, and answer the critical question of whether there is presently a fluid outer core [9, 10].

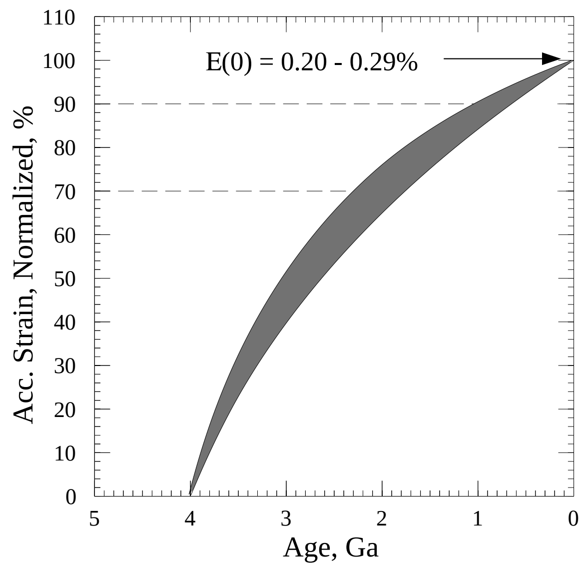

Figure 1. Model results for accumulated compressional strain as a function of age, normalized to present-day values. Envelope of solutions is shown (see text).

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